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I, JONNE YABSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. 2002953244 for a patent by COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION as filed on 10 December 2002.

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J R Yabsley

JONNE YABSLEY
TEAM LEADER EXAMINATION
SUPPORT AND SALES

AUSTRALIA

Patents Act 1990

Commonwealth Scientific and Industrial Research Organisation

PROVISIONAL SPECIFICATION

Invention Title:

A detection system

The invention is described in the following statement:

Technical Field

This invention concerns a system for the detection of concealed articles, substances and materials. For instance, the invention may be applied to the detection of concealed weapons, explosives, contraband, drugs and other articles, substances and materials in items such as aircraft baggage, airfreight or shipping containers.

Background Art

Numerous technologies based on X-rays, gamma-rays and neutrons have been proposed to tackle this problem (Hussein, E., 1992, Gozani, T., 1997). The most widely adopted technology is the X-ray scanner which forms an image of an item being examined by measuring the transmission of X-rays through the item from a source to a spatially segmented detector. X-rays are most strongly attenuated by dense, higher atomic number materials such as metals. Consequently, X-ray scanners are ideal for detecting items such as guns, knives and other weapons. However, as X-rays provide relatively little discriminating power between organic elements, the separation of illicit organic materials such as explosives or narcotics from commonly found, benign organic materials is often not possible.

Neutron/gamma-ray techniques, where the target item is irradiated with neutrons and the resulting spectrum of gamma rays is measured, have been widely explored (Gozani, T., 1997, Sawa et al., 1991). This method allows the ratios of key organic elements to be measured and in principle should allow the target item's contents to be identified. In practice, limited neutron source strength and low gamma-ray detection efficiency have made neutron/gamma-ray scanners too slow to be generally adopted. In order to localise the specific regions contributing to the measured gamma-ray signal fast nanosecond pulsed neutron beams are used, requiring the use of a very expensive and complex particle accelerator.

To overcome the problem of localisation, various neutron radiography systems have been considered, which measure the attenuation of a fast neutron beam passing through the target item. The fast neutron radiography technique has the advantage of direct measurement of transmitted neutrons and is therefore more efficient than techniques measuring secondary radiation such as neutron-induced gamma rays. Fast neutron radiography has the potential to determine the line-of-sight 'organic image' of objects. In contrast to X-rays, neutrons are most strongly attenuated by organic materials, especially those with high hydrogen contents.

The simplest approach is the fast neutron and gamma-ray transmission technique using radioisotope sources (Sowerby, 1985; Bartle, C.M., 1995). By combining

measurements of neutron and gamma ray transmission light elements (particularly hydrogen) can be determined independent of mass per unit area. However this technique has not been used for imaging.

Mikerov, V.I. et al, (2000) have investigated the possibility of fast neutron radiography using a 14 MeV neutron generator and luminescent screen/CCD camera detection system. Mikerov found that applications were limited by both the low detection efficiency of the 2 mm thick luminescent screen for fast neutrons and the high sensitivity of the screen to X rays produced by the neutron generator.

Neutron radiography systems using a 14 MeV generator and thermal neutron detection are commercially available (Le Tourneur, P., Bach, P. and Dance, W.E., 1998). However the fact that the fast neutrons are slowed down (thermalised) prior to performing radiography limits the size of the object being imaged to a few cm. No fast neutron radiography systems are commercially available that involve fast neutron detection.

Most work conducted with neutron radiography has been conducted in the laboratory using neutrons from nuclear reactors or particle accelerators that are not suited to a freight-handling applications (Lefevre, H.W, et al, 1996, Miller, T.G., 1997, Chen, G. and Lanza, R.C., 2000, Brzosko, J.S. et al, 1992). In an attempt to extract elemental composition from fast neutron radiography, the group from the University of Oregon (Lefevre, H.W, et al, 1996) have investigated a complex neutron transmission method that involves a broad-band (white) spectrum of nanosecond pulsed neutrons with energies up to 8.2 MeV. However this method has been shown to have limited performance and the large accelerator-based hardware required is a serious handicap.

Fast neutron radiography systems can provide discrimination between organic and inorganic materials, but have limited capabilities for identification of the exact organic material present. To overcome this limitation, systems using multiple neutron energy sources, together with detectors with the means for distinguishing between the different neutron energies have been proposed (Chen, G. and Lanza, R.C., 2000, Buffler, 2001). The key drawbacks of these systems have been their reliance on complex, energy-discriminating neutron detectors and/or their use of sophisticated, high-energy accelerator-based neutron sources.

<u>Summary of the Invention</u>

The invention is a system for the detection of concealed articles, substances and materials, the system including:

A source of neutrons and a source or X-rays or gamma-rays to irradiate an object.

A two-dimensional detector to sense neutrons and X-rays or gamma-rays after passing through the object and produce a first output related to the neutron count rate in each pixel location of the detector, and a second output related to the X-ray or gamma-ray count rate in each pixel location of the detector.

A processor to receive the first and second outputs and to generate an image output for display.

A sealed-tube or other compact neutron generator may produce either 14 MeV neutrons via the deuteron-triton fusion reaction or 2.45 MeV neutrons via the deuteron-deuteron fusion reaction.

Two tubes may be used, one to produce 14 MeV neutrons via the deuteron-triton fusion reaction, and a second to produce 2.45 MeV neutrons via the deuteron-deuteron fusion reaction. The measurement of neutron transmission at a second energy can be used to significantly enhance the capability of the single energy transmission technique.

In a variation of the dual energy neutron technique that may enhance the application of the technique for illicit substance detection, neutron radiography is performed at two neutron energies from a single deuteron-deuteron (D-D) neutron generator by utilising neutrons of different energies that are emitted at specific angles to the deuteron beam. The proposed D-D dual energy neutron radiography technique has the potential to provide separate images primarily sensitive to the hydrogen and oxygen densities (Chen and Lanza, 2000) together with a separate gamma ray density image.

An X-ray tube, Bremsstrahlung or radioisotope source may produce X- or gamma-rays of sufficient energy to substantially penetrate through the item to be imaged.

The same detector may be able to sense both neutrons and X-rays or gamma-rays. Energy discrimination may be used to distinguish the signals or the detector can operate sequentially on neutrons and X-rays or gamma rays. Optionally, separate detectors may be used to sense each source.

The object may be scanned between the neutron source and detector. As an object to be imaged is scanned, two or more outputs are obtained measuring the transmission of either 14 MeV or 2.45 MeV neutrons, or both, and X- or gamma-rays through the object. The object may be scanned more than once if only a single detector is employed.

A computer may be used to receive the transmission outputs from the detectors, perform image processing and display the images to an operator on a computer screen. The computer may also be able to perform automatic material identification.

For instance, the transmission outputs may be converted to mass-attenuation coefficient images for each pixel for display on a computer screen with different pixel values mapped to different colours. In particular mass-attenuation coefficient images may

be obtained from the count rates measured from the transmissions for each of the 14 MeV neutrons, 2.45 MeV neutrons and X- or gamma-rays.

Analysis of the mass-attenuation coefficient images allows a variety of inorganic and organic materials to be distinguished. Such analysis may include forming cross section ratio images between pairs of mass attenuation coefficient images. Cross section ratio images may be formed from the mass-attenuation coefficient images of the 14 MeV neutrons and the 2.45 MeV neutrons, the 14 MeV neutrons and the X- or gamma-rays, and the 2.45 MeV neutrons and the X- or gamma-rays. Advantageously, such images are independent of the mass of the object.

An image may be formed that is a linear combination of two cross section ratio images. The proportions in which the cross section ratio images are combined may be operator adjusted to maximise contrast and sensitivity to a particular object being examined in the image.

Two regions in an image may be identified which contain a first substance, but only one of the regions may contain a second substance. By performing cross section subtractions the image of the first substance may be effectively removed leaving the image of the second substance available for identification. The mass of the second substance may be obtained from the X- or gamma-ray transmission data.

The invention may be applied to non-invasive examination of containers or packages the detection of contraband, explosives and other articles, substances and materials. It may provide improved specificity for contraband materials, such as organic materials in primarily inorganic matrices, as well as the detection and identification of specific classes of organic material. It is particularly suited for the detection of explosives, narcotics and other contraband items concealed in aircraft baggage, airfreight containers and shipping containers.

It may also provide increased automation of the inspection process, with reduced reliance on human operators.

Further, it may provide a fast scanning rate so that a high throughput can be achieved. It is simple, low-cost and uses safe radiation sources; and simple, low-cost radiation detection systems. It may operate with a high detection rate and low false alarm probability.

Brief Description of Drawings

Several examples of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a horizontal cross-section through the centre of the scanner;

Figure 2 is a plot of a large number of benign, narcotic and explosive materials in terms of the ratio 14 MeV neutron cross-section to gamma-ray cross section;

Figure 3 is a plot of a large number of benign, narcotic and explosive materials in terms of two cross-section ratios, namely 2.45 MeV neutron/14 MeV neutron cross-sections versus 14 MeV neutron/X- or gamma-ray cross-sections;

Figure 4 is a computer model of an air freight container;

Figures 5a is a simulated X-ray image; Figure 5b is a simulated 14 MeV neutron image; and Figure 5c is a simulated cross-section ratio image;

Figures 6a is a simulated count rate DT neutron image of a suitcase; Figure 6b is a simulated count rate image of a DD neutron image of the suitcase; Figure 6c is a simulated count rate X ray image of the suitcase; Figure 6d and 6e is a DT/X-ray cross section image and Figure 6e is a DD/DT cross-section image;

Figure 7 is a computer model of a further air freight container;

Figure 8a is a simulated 14 MeV neutron image of the air freight container illustrated in Figure 7; and Figure 8b is an X-ray image respectively of the same container; and

Figure 9 is an enlarged version of Figure 8c with target regions marked (see text).

Best Modes for Carrying out the Invention

Figure 1 illustrates the overall layout of the scanner 10. Neutrons or gamma rays are emitted from the radiation sources 11. A radiation detector 12 is situated in the vicinity of the radiation source.

Both radiation source 11 and detector 12 are situated inside a radiation shield 16. This shield is formed from a material that attenuates and absorbs both X- or gamma-rays and neutrons. Typical shielding materials include boron-loaded paraffin wax, polyethylene beads mixed with a binder, water or concrete. A tunnel 17 passes through the radiation shield and is situated between the radiation source 11 and detector 12.

The radiation shield 16 serves two purposes. Firstly, it provides radiological protection for operators of the scanner or other persons in its immediate vicinity. Secondly, collimating slits 14 and 15 cut into the shield serve to define a fan shaped radiation beam, directed from the source towards the radiation detector. The detector collimating slit 15 and detector 12 extend the full height of the tunnel.

The radiation detector 12 is capable of detecting both neutrons and X- or gamma-rays with high efficiency. Note that gamma rays from D-T or D-D neutron generators are of low energy and therefore do not interfere with the detection of either 14 or 2.45 MeV neutrons. In particular there is no need for complex pulse shape discrimination electronics

(Shani, 1985, Bartle, 1995). The detector 12 is also capable of detecting the position of the arriving radiation. The detector 12 output is segmented into a two-dimensional array of pixels; the term image-frame is used to describe the two-dimensional array containing the number of counts measured in each pixel, accumulated over a fixed time interval.

The radiation detector 12 comprises an array of plastic scintillator rods (not shown), with each rod corresponding to a single pixel in the image-frame. In the primary embodiment, the scintillation light produced in a rod by an incident neutron or X- or gamma-ray is detected by a photodiode or photomultiplier attached to the end of the rod. In a first variation, light from a row or column of scintillator rods is collected by a wavelength shifting optical fibre and transmitted to a photodiode or photomultiplier. By indexing the row and column producing the light pulse, the scintillator rod intercepting the radiation can be inferred. In a second variation, light from a multiplicity of scintillator rods is collected by wave-length shifting or transparent optical fibre and directed to a multi-anode photomultiplier tube or position sensitive photodiode, to allow multiple scintillator rods to be read out by a single detector. In a third variation, light from several rows or columns of scintillator rods is collected by wave-length shifting optical fibres and transmitted to a position sensitive photodiode or multi-anode photomultiplier. By indexing the row and column producing the light pulse, the scintillator rod intercepting the radiation can be inferred.

For both single and dual energy neutron transmission a radioisotope producing high-energy gamma-rays such as cobalt-60 or cesium-137 is used as the gamma-ray source. In a variation, a high-energy X-ray tube or Bremsstrahlung electron linear accelerator source is used as a high-energy X-ray source.

In the primary embodiment, the radiation sources 11 are situated on one side of the object 13 to be examined and the detectors 12 on the opposite side. In a first variation, the sources 11 are situated above or below the object 13 to be examined, with the detectors 12 positioned on the opposite side (below or above respectively). In a second variation, the sources 11 and detectors 12 can be rotated around the object 13 to be examined to allow multiple views to be obtained. In a third variation, multiple sets of sources 11 and detectors 12 are used to allow simultaneous collection of multiple views of the same object 13. In a fourth variation, multiple sets of detectors 12 are disposed around a central source 11 to allow views of multiple objects 13 to be acquired simultaneously.

In operation, objects 13 that are to be scanned are passed through the tunnel 17 on a conveyor belt or winched or pushed through using a suitable mechanism. As the object 13 passes through the tunnel 17, a series of image-frames is collected. The time between frames is sufficiently short that blurring of the image due to motion of the scanned object

13 is less than the width of a single pixel of the image. Once the scan is completed, the series of image frames is assembled into a single image of the scanned object 13. Separate images are collected when the radiation source is emitting 14 MeV neutrons, 2.45 MeV neutrons and X- or gamma-rays.

In the primary single neutron energy embodiment, the radiation source 11 comprises two separate generators of radiation, one producing either 14 MeV or 2.45 MeV neutrons and the other producing high-energy X- or gamma-ray radiation. The neutron source is a sealed tube neutron generator or another compact source of a similar nature, producing neutrons via D-T or D-D fusion reactions.

The two radiation sources are operated sequentially as the object 13 is scanned through the analyser. In a first variation, the object 13 is scanned through the analyser twice, with one source being operated for each scan. In a second variation, each source has a separate associated detector and the object is scanned only once. In a third variation, the two radiation sources are operated at the same time, a single detector is used and energy discrimination is used to separate the signals due to neutron and X- or gamma-rays.

In the variation (dual neutron energy embodiment), the radiation source 11 comprises three separate generators of radiation, one producing 14 MeV neutrons, one producing 2.45 MeV neutrons and the last producing high-energy X- or gamma-ray radiations. A second proposed variation is where the two neutron energies are generated from a single deuteron-deuteron (D-D) neutron generator by utilising neutrons of different energies that are emitted at specific angles to the deuteron beam. The neutron sources are sealed tube neutron generators or other compact sources of a similar nature, producing neutrons via D-T and D-D fusion reactions.

The three radiation sources are operated sequentially as the object is scanned through the analyser. In a first variation, the object is scanned through the analyser three times, with one source being operated for each scan. In a second variation, each source has a separate associated detector and the object is scanned only once. In a third variation, two or more of the radiation sources are operated at the same time with a single detector, and energy discrimination is used to distinguish the signals from the high energy neutrons, low energy neutrons and X- or gamma-rays.

Image Formation and Interpretation

The following discussion applies directly to the dual energy fast neutron transmission embodiment for 14 MeV and 2.45 MeV. However the discussion also applies to the dual energy transmission at different energies to 2.45 and 14 MeV and to single energy neutron transmission. However for single energy neutron transmission only two

count rates (neutron and X-ray/gamma-ray) are measured at each pixel rather than three in the case of dual neutron transmission, and only one-cross-section ratio can be calculated.

Suppose that the count rates in a particular pixel from each image are r_{14}, $r_{2.45}$ and r_X respectively. These rates are related to the (unknown) mass of material m between the source and detection points and the (unknown) mass attenuation coefficients of this material for 14 MeV neutrons, 2.45 MeV neutrons and X- or gamma-rays, written as μ_{14}, $\mu_{2.45}$ and μ_X respectively, by the relations

$$r_{14} = R_{14}\exp(-m\mu_{14}) \quad (1)$$
$$r_X = R_X\exp(-m\mu_X) \quad (2)$$
$$r_{2.45} = R_{2.45}\exp(-m\mu_{2.45}) \quad (3)$$

where R_{14}, $R_{2.45}$ and R_X are respectively the count rates for 14 MeV neutrons, 2.45 MeV neutrons and X- or gamma-rays when no intervening object is present.

The cross-section ratios can be calculated directly:

$$\mu_{14}/\mu_X = \log(r_{14}/R_{14})/\log(r_X/R_X) \quad (4)$$
$$\mu_{2.45}/\mu_{14} = \log(r_{2.45}/R_{2.45})/\log(r_{14}/R_{14}) \quad (5)$$

Note that both of these ratios are independent of the mass of material present in the beam between the source and detector.

The cross-section ratios given by equations (4) and (5) allow a wide variety of organic and inorganic materials to be distinguished.

Figure 2 illustrates the variation in the ratio of 14 MeV neutron cross-sections/gamma-ray cross-sections for a variety of materials. The determination of this ratio allows a wide variety of inorganic and organic materials to be distinguished.

Figure 3 illustrates the ratio of 2.45 MeV neutron cross-section to 14 MeV neutron cross-section versus the ratio of 14 MeV neutron cross-section to X- or gamma-ray cross-section, for a selection of materials. The availability of two cross-section ratios further enhances the ability of the invention to distinguish between different materials. Consequently, analysis of the three mass-attenuation coefficient images allows information about the contents of the object being examined to be inferred.

The information contained in the count-rate images with pixel values given by equations (1), (2) or (3) and the cross-section ratio images with pixel values given by

equations (4) or (5) can be processed in several ways to facilitate the detection of contraband materials.

In the primary embodiment the images would be displayed on a computer screen, with different pixel values mapped to different colours. A suitably trained operator would view and interpret the coloured images.

Figures 4 and 5 illustrate the use of a single energy 14 MeV plus gamma-ray scanner. Figure 4 shows a computer model of an air freight container 20 containing the following items: a wooden case 22 filled with metal parts of uniform density and additionally containing a package of drugs 24; two ceramic cylinders 26, 28, with the left-hand one 26 hollowed out and containing drugs 30; and a stack of three crates 32, 34, 36 containing clothing, with a third package of drugs 38 concealed in the top crate 32. The air freight container is 3m long x 1.8m high by 1.6m thick.

Figures 5a, 5b and 5c show simulated X-ray, 14 MeV neutron images and a cross-section ratio image respectively, given by equation (4). In the X-ray image Figure 5a, the drugs concealed in the crate 22 of metal parts and in the ceramic cylinder 26 are invisible as in both cases it is assumed that the bulk density of the drugs is similar to that of the displaced materials. The package of drugs 38 concealed in the clothing container 32 is visible as its density is significantly higher than the surrounding material.

In contrast, all three packages of drugs 24, 30, 38 can be seen in both the 14 MeV neutron image, Figure 5b and the cross-section ratio image Figure 5c. The 14 MeV image shows the contrast between the two ceramic cylinders 26, 28 and also the outline of the drug packages 24, 38 contained in the crates of metal parts 22 and clothing 32 respectively. The neutron/gamma-ray cross-section ratio image Figure 5c provides additional information, namely that all three packages have a high neutron cross-section and hence are probably of organic origin.

Figure 6 illustrates the additional benefit of using dual neutron energies, consider the simulated images of a suitcase 40 shown Figures 6a to 6e. Images 6a to 6c correspond to equations (1) (2) and (3) and show the transmission of 14 MeV neutrons, 2.45 MeV neutrons and X- or gamma-rays respectively. Images 6d to 6e correspond to equations (4) and (5) and show the DT/X-ray and DD/DT cross-sections respectively.

The suitcase 40 is filled with clothing composed of cotton and wool, and contains various benign and suspicious objects. Bottle 42 contains water and bottle 44 contains spirits. The three blocks visible on the lower right of the suitcase 40 are a paperback book 46, heroin 48 and RDX explosive 50. A gun 52 is also visible in the upper right of the suitcase 40.

From a conventional X-ray image 6c, it is difficult or impossible to distinguish between the contents of the two bottles 42, 44, or the three packages 46, 48, 50 on the right hand side of the case that have similar densities. The neutron images 6a, 6b provide more contrast between the different materials, but the best results are obtained from the cross-section ratio images 6d and 6e. In particular, the book 46 virtually disappears as paper has a similar composition to the surrounding clothing, whereas the drugs 48 and explosive materials 50 can be clearly distinguished. A clear difference is also seen between the bottles containing water 42 and spirits 44.

In a first variation of the dual neutron transmission method, the operator would form a new image that is a linear combination of the two cross-section ratio images. The proportions in which the two images are combined are adjusted by the operator to maximise contrast and sensitivity for contraband materials and to minimise the effects of clutter resulting from overlapping objects.

As an example, consider the cargo container 60 illustrated in Figure 7. This contains a large box 62 (size 3 m long by 1.8 m wide by 1.8 m high) of food-stuffs, four boxes containing computer equipment 64 and four horizontal steel pipes 66. The upper left hand computer box 64 contains two packages of drugs 68.

Figures 8a to 8b illustrate simulated 14 MeV neutron and X-ray images respectively of this container 60, taken from the side. Due to their high density, the steel pipes 66 dominate the images, making it hard to see the outlines of the computer equipment 64. However, by forming a single image, Figure 8c, from the two cross-section ratio images given by equations (4) and (5), it is possible to remove the "clutter" associated with the steel pipes 66, to reveal the computer boxes 64.

The pixel values of the new image, I_C can be written in terms of the pixel values from images 4 (I_4) and 5 (I_5) through the relation

$$I_C = \cos(\theta)I_4 + \sin(\theta)I_5 \qquad (6)$$

By varying the single parameter θ, the operator can select the image that offers the best contrast for the object of interest.

This approach can be understood with reference to Figure 3. Choosing a linear combination of images (4) and (5) is equivalent to colouring image pixels according to their distance from an arbitrarily orientated line drawn on Figure 3. By choosing this line to be parallel to two selected materials, any combination of these materials is coloured the same. In the example discussed, the line is chosen to be parallel to a line connecting steel and the polystyrene packaging of the computers. In this way, the steel pipes can be made to

largely vanish where they pass in front of the computers. The lower image of Figure 8 shows the results of this process.

In a second variation, the operator identifies two regions in the object image. The first surrounds a potentially suspicious material that the operator wishes to identify. The second region, which will typically be in the neighbourhood of the first region, is selected by the operator as containing substantially the same over- or underlying materials as the first region, with the exception of the suspicious material of interest. From differences in the count rates for 14 MeV neutrons, 2.45 MeV neutrons and X- or gamma-rays in the two regions, it is possible to calculate the cross-section ratios given in equations (4) and (5) for the suspicious material alone – that is, without the contribution of over- and underlying material. Automatic identification of this material can then be performed, by reference to a database of known material cross-section ratios. The mass of the suspicious material can also be calculated from the X- or gamma-ray transmission data, as the attenuation coefficients for high-energy X- or gamma-rays depends primarily only on the mass of material present.

As an example, consider the cargo container 60 described above. Figure 9 shows an enlarged version of the combined image shown in Figure 8c. The operator notes that the package 68 above the top left computer 64 (region (1) in Figure 9) is different in appearance from the packages on top of the other three computers 64. The operator notes that the point marked (2) in Figure 9 is likely to contain the same under- and over-lying material as region (1), with the exception of the suspicious package itself. Once the operator has identified these two regions, the computer can perform the necessary cross-section subtractions and determine the likely constituents of the unknown package.

In a third variation, the process described in the third embodiment is totally automated, with image processing/object recognition software selecting the two regions. If an undesirable class of material is identified, an alert is sounded and the bag or freight container in question can be unpacked and examined.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.

Dated this tenth day of December 2002

Commonwealth Scientific and Industrial Research Organisation
Patent Attorneys for the Applicant:
F B RICE & CO

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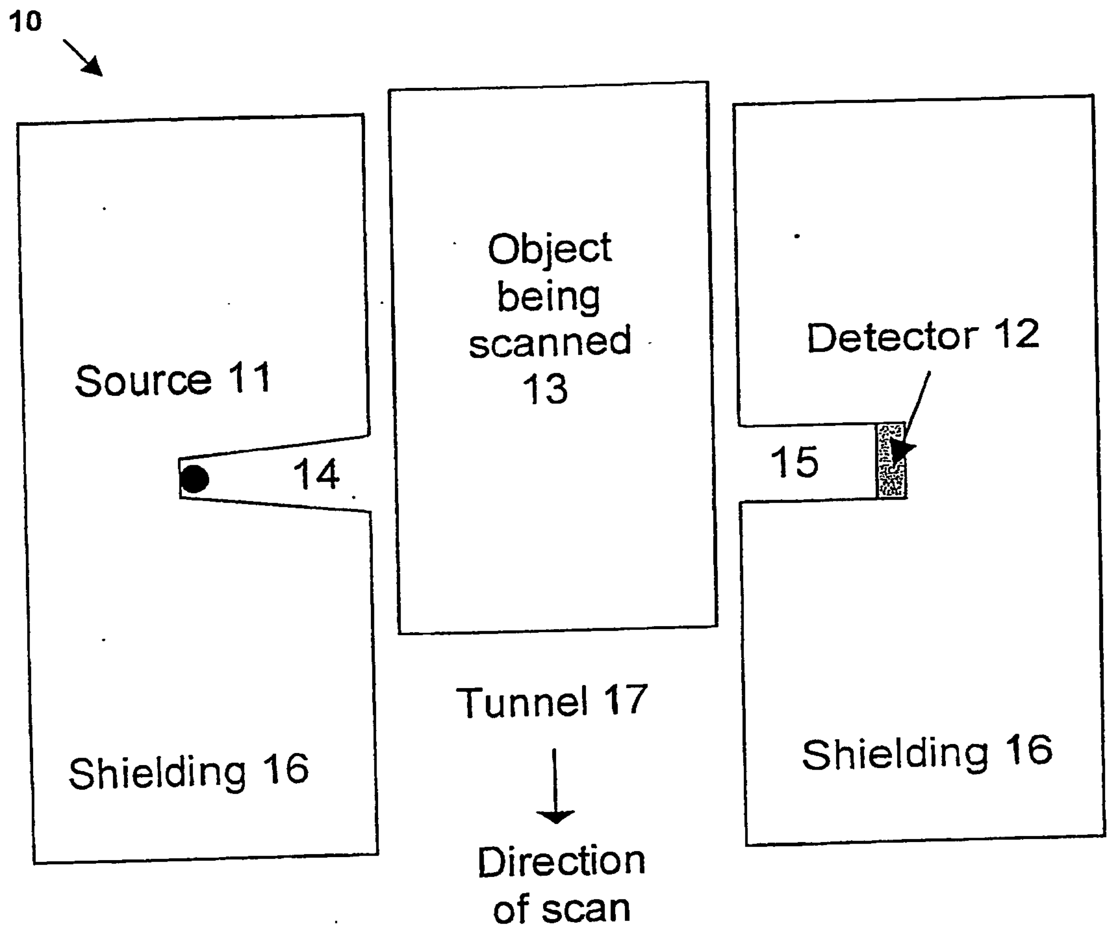
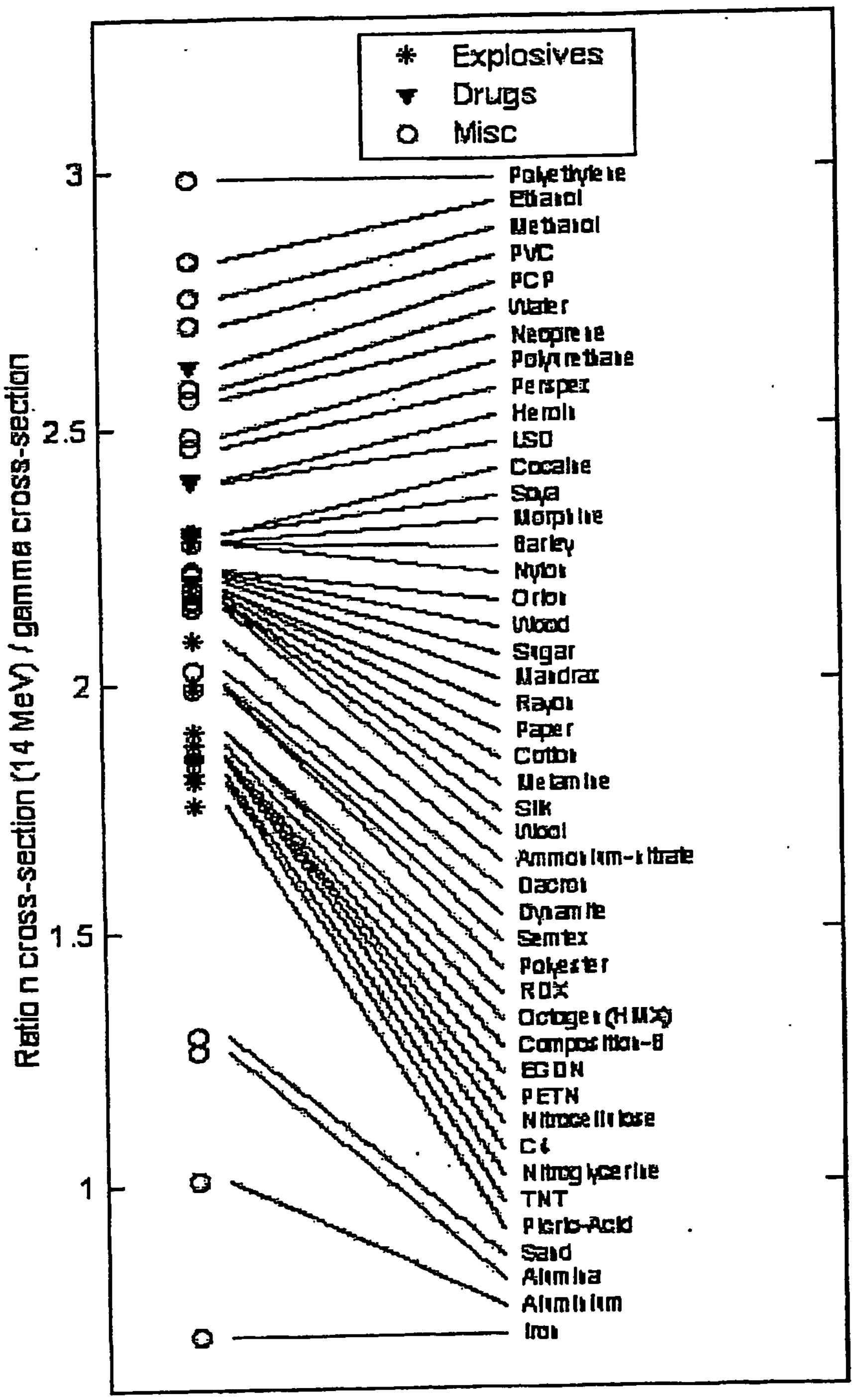

10
Source 11
14
Shielding 16
Object
being
scanned
13
Tunnel 17
Direction
of scan
Detector 12
15
Shielding 16

Fig. 1



Explosives
Drugs
Misc
3
2.5
2
1.5
1
Ratio n cross-section (14 MeV) / gamma cross-section
Polyethylene
Ethanol
Methanol
PVC
PCP
Water
Neoprene
Polyurethane
Perspex
Heroin
LSD
Cocaine
Soya
Morphine
Barley
Nylon
Orlon
Wood
Sugar
Mandrax
Rayon
Paper
Cotton
Melamine
Silk
Wool
Ammonium-nitrate
Dacron
Dynamite
Semtex
Polyester
RDX
Octogen (HMX)
Composition-B
EGDN
PETN
Nitrocellulose
C4
Nitroglycerine
TNT
Picric-Acid
Sand
Alumina
Aluminium
Iron

Fig. 2

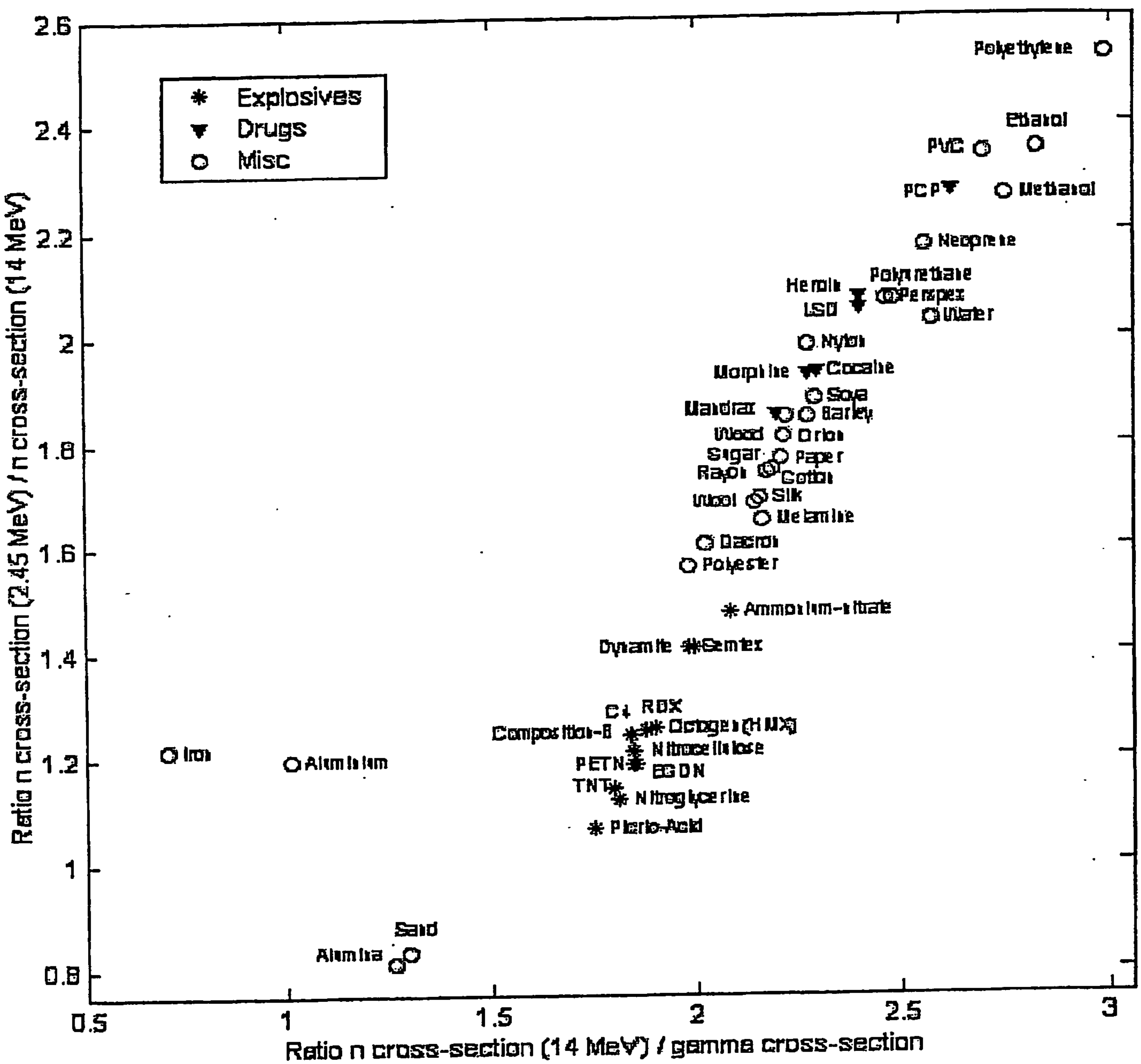

Explosives
Drugs
Misc
Polyethylene
Ethanol
PVC
PCP
Methanol
Neoprene
Heroin
LSD
Polyurethane
Perspex
Water
Nylon
Morphine
Cocaine
Soya
Mandrax
Barley
Wood
Orlon
Sugar
Paper
Rayon
Cotton
Wool
Silk
Melamine
Dacron
Polyester
Ammonium-nitrate
Dynamite
Semtex
C4
RDX
Composition-B
Octogen (HMX)
Nitrocellulose
PETN
EGDN
TNT
Nitroglycerine
Picric-Acid
Iron
Aluminium
Sand
Alumina
Ratio n cross-section (2.45 MeV) / n cross-section (14 MeV)
Ratio n cross-section (14 MeV) / gamma cross-section
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.5
1
1.5
2
2.5
3

Fig. 3

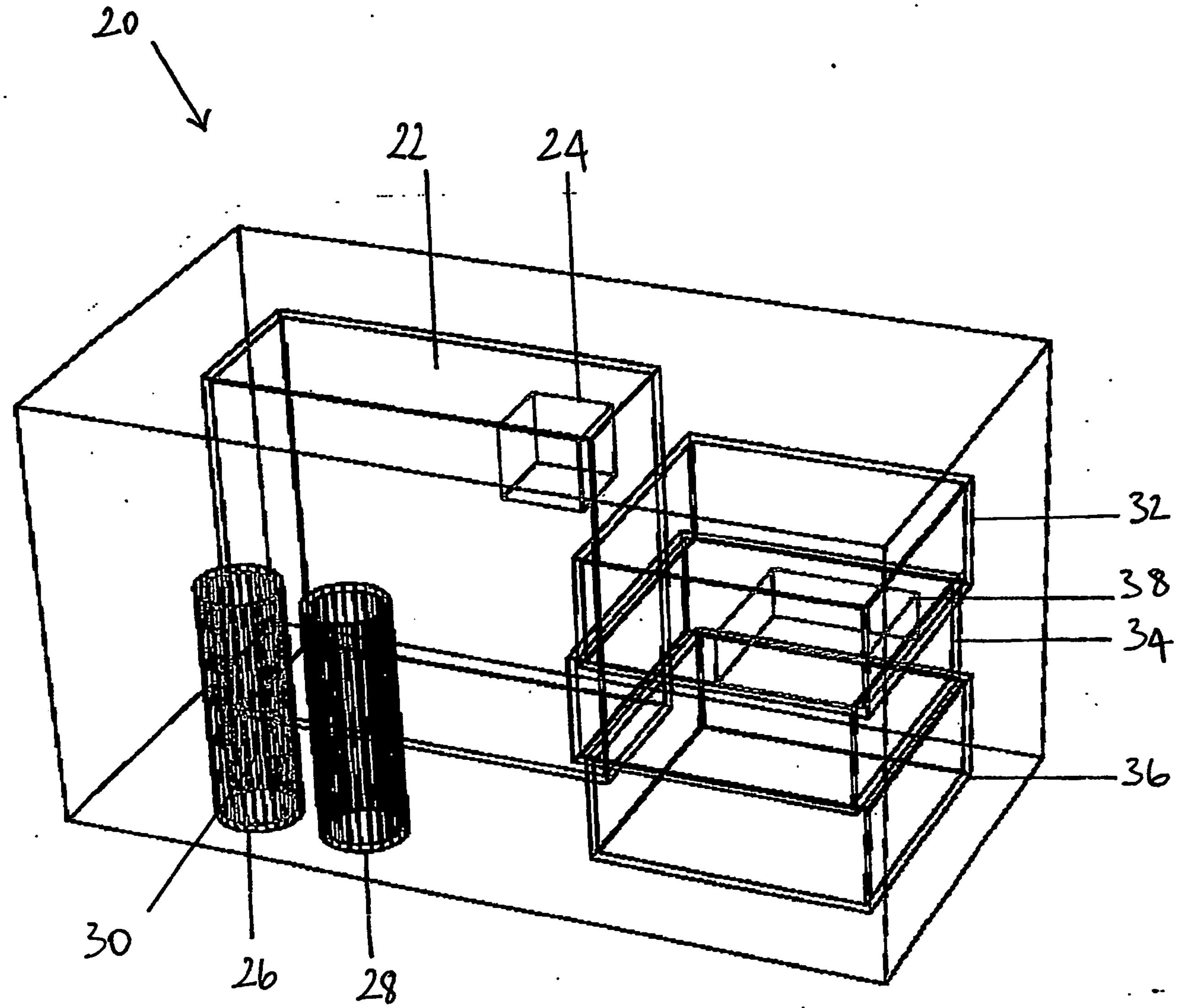


Fig. 4

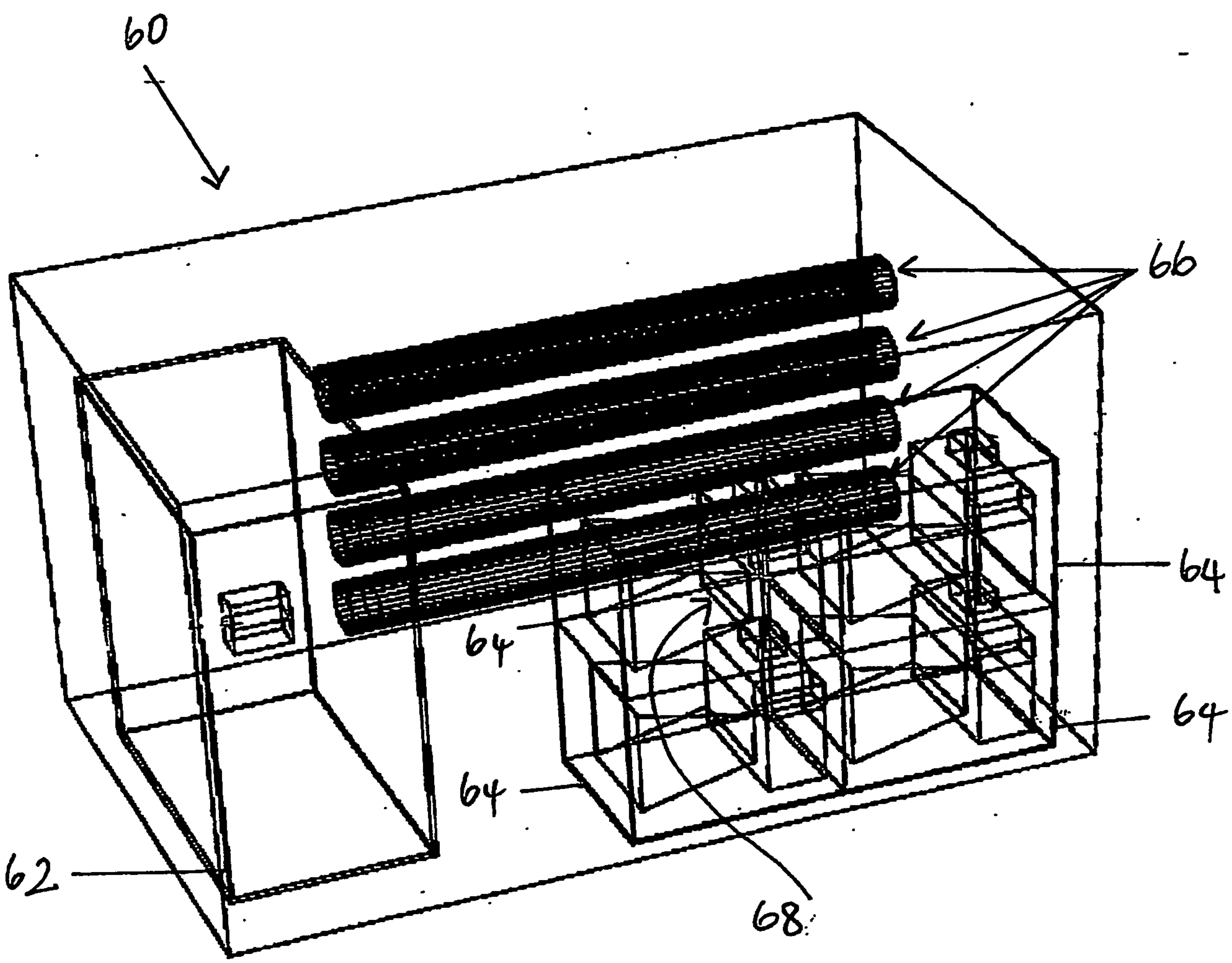
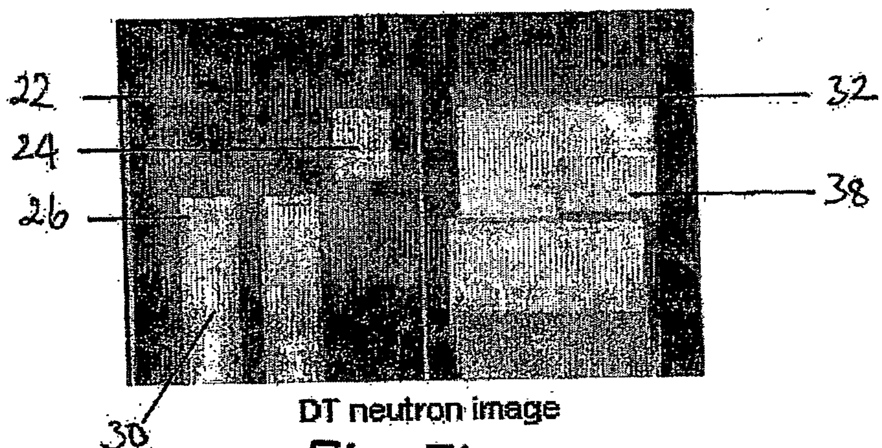


Fig. 7

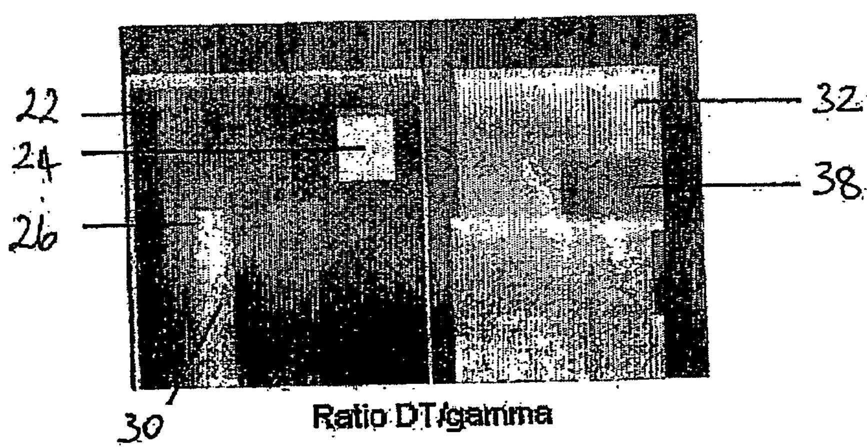
X-ray image

Fig. 5a



DT neutron image

Fig. 5b



Ratio DT/gamma

Fig. 5c

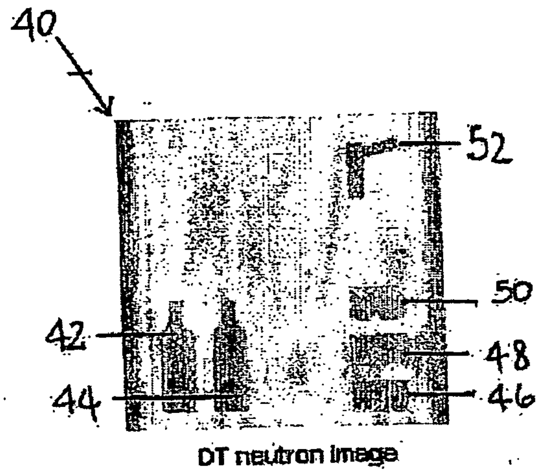


Fig. 6a

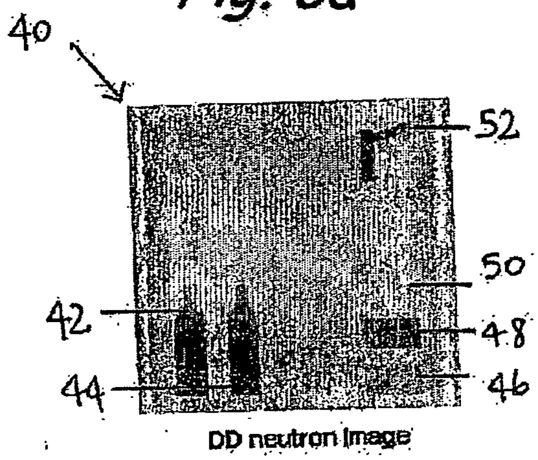


Fig. 6b

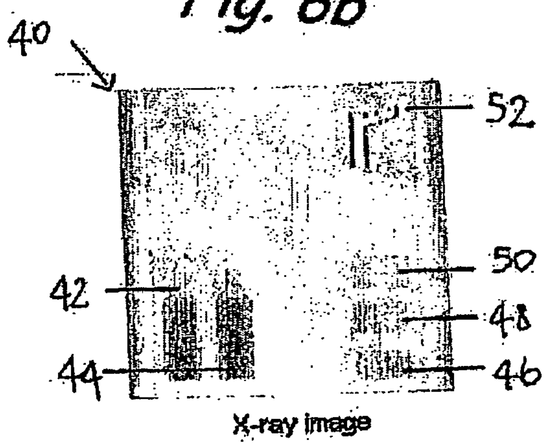


Fig. 6c

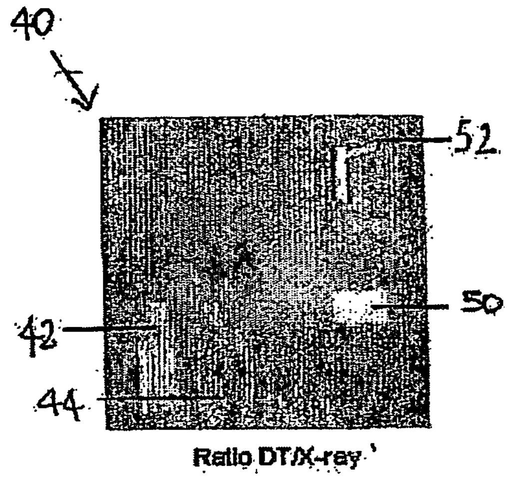


Fig. 6d

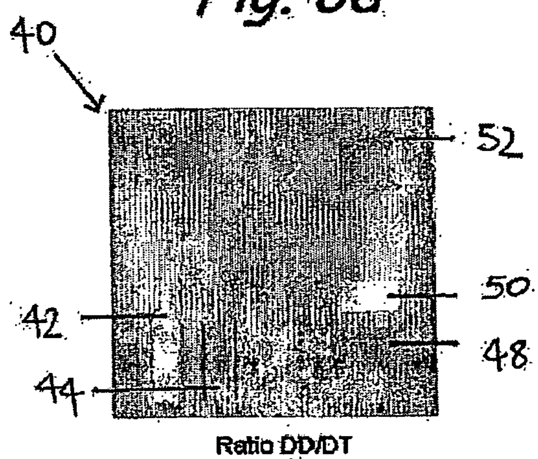


Fig. 6e

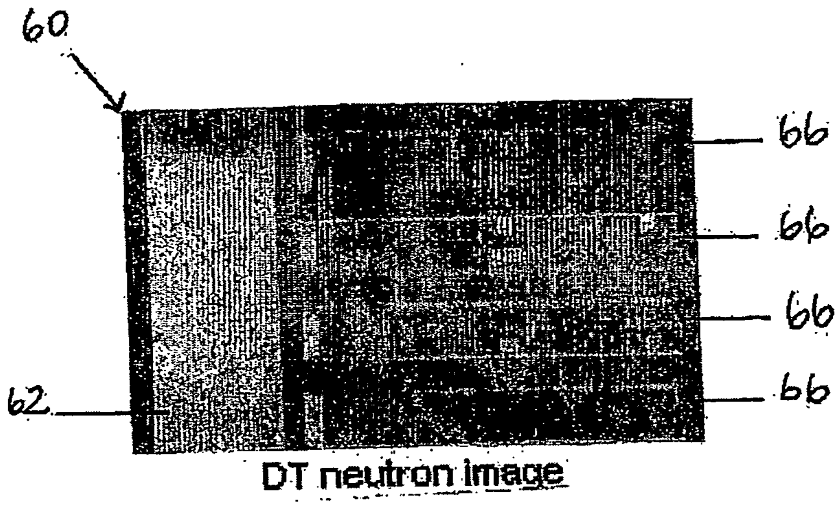


Fig. 8a

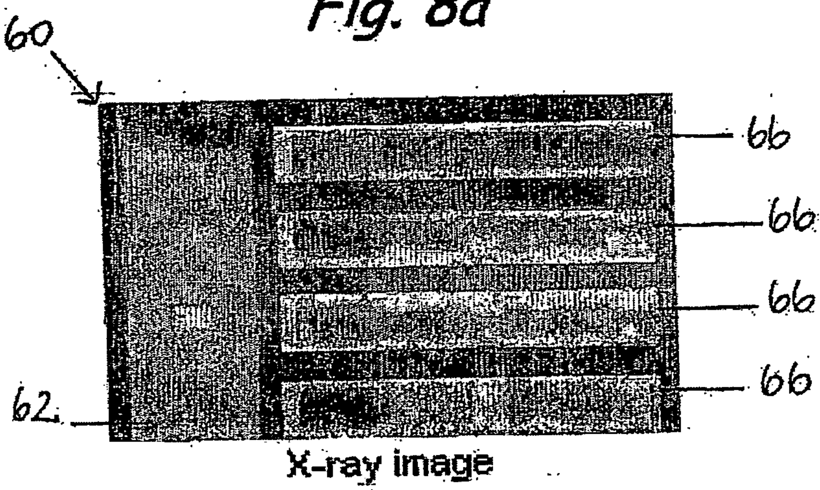


Fig. 8b

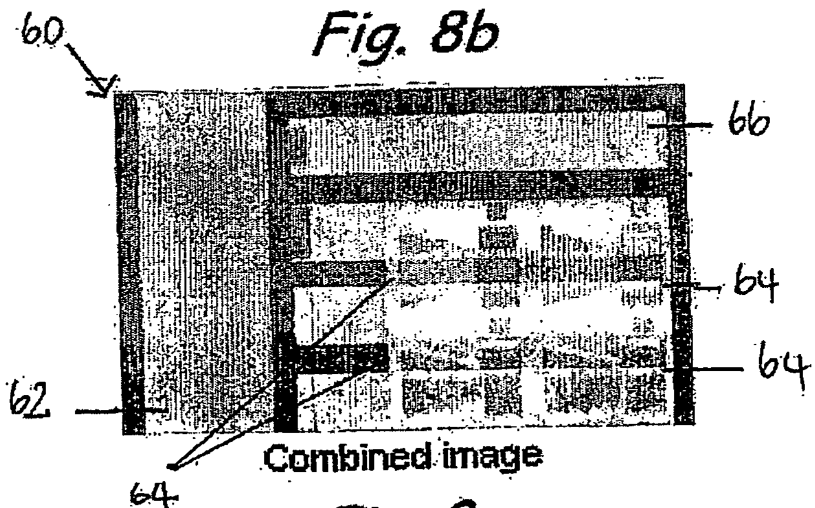


Fig. 8c

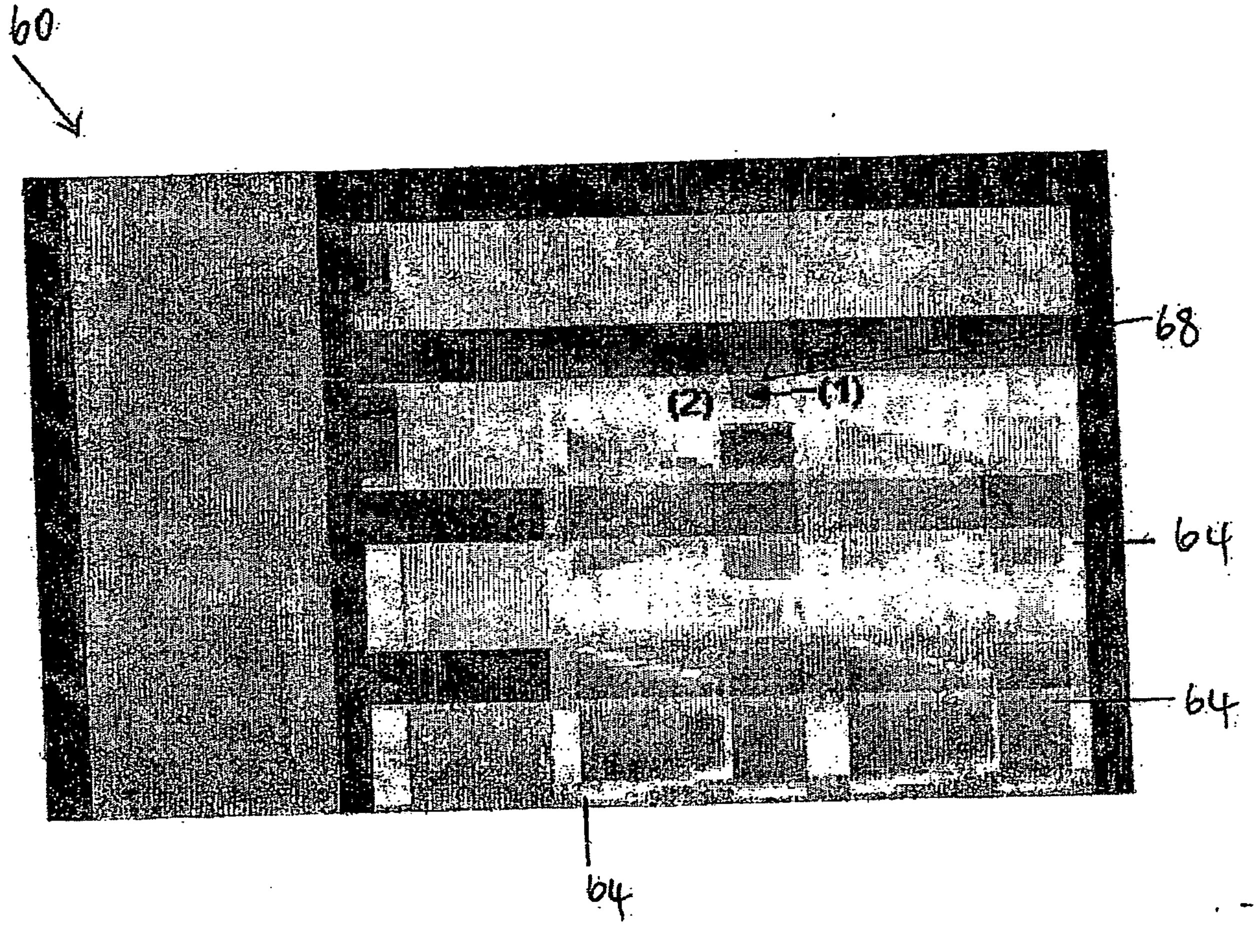


Fig. 9